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Thank you for your interest in Piedmont's FaeSTER enzymatic biodiesel process. This information should provide you with more data on the process, how it may be appropriate for your production capabilities, and what the next steps are to implement the enzymatic process in your biodiesel plant.

Summary

The FAeSTER process is a patent pending, fully continuous esterification technology using immobilized or liquid enzymes. The enzymes can be reused for multiple reactions, and we have achieved a catalyst cost of $0.15 per gallon processed feedstock. This process is a direct replacement for acid esterification using sulfuric acid, or solid acid catalysts, and generates a dry (<1500ppm water), low FFA (<1%) feedstock ready for transesterification. For very high FFA feedstocks like acid distillates or brown grease, this process is particularly cost effective. What differentiates FAeSTER from normal enzymatic esterification is our ability to continuously remove moisture to drive the esterification reaction towards methyl ester production.We are currently working on our first commercial plant using the FAeSTER process at our biodiesel production facility in Pittsboro, NC. Later this spring, we will invite interested producers to see the plant and discuss the theory of operation. Commercial units should be available for sale in 2012.

As announced at the National Biodiesel Conference in February of 2012, we have successfully scaled up our enzymatic transesterification process in a commercial production setting. We are available to assist other biodiesel producers interested in implementing enzyme catalysts for existing or future transesterification production facilities. It is our assertion that enzyme based transesterification does not require significant capital upfitting. We do see the equipment to run FAeSTER process as a necessary component of full enzyme based biodiesel production process. Independent of feedstock, enzyme transesterification yields 2-3% FFA. The FAeSTER process can easily esterify or “polish” this FFA directly in methyl esters. As a producer, you can first invest in the FaeSTER equipment for feedstock pretreatment. Or you can implement a fully enzymatic biodiesel solution using liquid enzymes for transesterification and FAeSTER to polish residual FFA into ASTM grade fuel.

Next Steps

We will put on a biodiesel workshop with an large enzymatic biodiesel component in the spring of 2012. This is a chance to view our plant and discuss the data from the enzymatic process, and the workshop will be tailored for industry producers interested in learning more. In addition, there will be Novozymes' scientists, industry experts, and plenty of time for discussion among colleagues. We are inviting companies interested in the FAeSTER process to send us a sample to test on a lab scale. We already have extensive data on yellow grease (used cooking oil), brown grease, corn oil, and palm fatty acid distillate, so other feedstock types would be preferable.

If you would like to have your feedstock tested, you have questions, or want more information, please contact Rachel Burton at rachel@biofuels.coop.

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Enzymatic Biodiesel Background

Enzymes have been used as a catalyst for biodiesel production for years. The body of work is available in the technical literature. Fjerbaek, 2008 and Ranganathan, 2007 are two good summary papers which describe in detail the benefits and problems associated with enzymatic production.

Piedmont Biofuels has been working on enzymatic biodiesel production for over 3 years. In that time, we have successfully addressed many of the technical hurdles which have plagued other researchers.

Benefits of Enzymatic Processing

- No soap formed during the reaction
- High quality glycerin
- Very little excess methanol
- Can esterify and transesterify
- No caustic chemicals required
- Reduces or eliminates post processing (water wash, ion exchange, etc.)

Problems with enzymatic production	Solutions from the literature, other companies	Solutions from Piedmont Biofuels
Very slow reaction times	Use enzymes with faster reaction rates for transesterification, use cosolvents, multi-stage glycerol removal	Focused on esterification first, which is much faster than transesterification, more robust, and is needed by the industry NOW. Worked with Novozymes to use new liquid enzymes which are both robust and fast for transesterification.
Unable to achieve actual ASTM and EU specifications	Almost no work done here – researchers report conversion to esters, generally ignore commercial ASTM specifications like acid number and bound glycerin.	Achieved full ASTM specification for soy and yellow grease *without* using post-processing techniques for monoglyceride and FFA removal. Developed and tested a patent-pending process for achieving ASTM specification acid number on finished biodiesel *without* caustic stripping.
High catalyst cost	Reuse the enzyme for 60 – 100 batches. No reuse data is commercially viable	Reused the enzyme in a continuous process for months. Work with Novozymes to reduce enzyme production costs. Overall, achieved $0.15/gal catalyst cost and still running.
Untested on very low quality feedstocks with impurities and other "real world" feedstocks	Tested waste fish oils, yellow greases, animal fats, mostly in relatively short batch reuse systems	Tested yellow grease, brown grease for esterification using full enzyme life trials to achieve $0.15/gal catalyst cost.
Enzyme deactivation due to the alcohol	Use ethanol and other higher alcohols and/or cosolvents to reduce the impact	Use continuous methanol addition to minimize alcohol/enzyme contact while maintaining the maximum possible reaction rate
Enzyme deactivation due to glycerol	Add cosolvents, multi-stage glycerol removal, use different carriers	Shifted from immobilized enzymes to liquid formulations for both esterification and trans.

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Fatty Acid Esterification using Enzymes – the FAeSTER Process

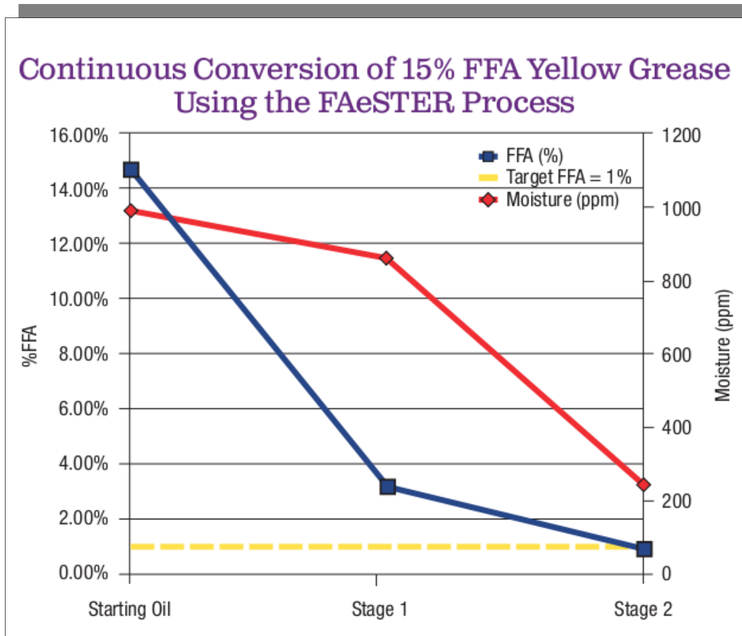

Figure 1: FAeSTER (continuous) with yellow grease

The FAeSTER process uses Candida Antarctica Lipase B (CALB) enzyme from Novozymes to continuously esterify fatty acids in oil or biodiesel. The enzyme can be immobilized on a support which is 0.3 – 0.7mm. The enzyme and support remain in the reactor and do not leach into the feed stream. The enzyme is now available in a liquid format- we are optimizing the process for both the immobilized and liquid enzymes. It uses continuous moisture removal to both increase the reaction rate and to achieve the lowest possible amount of free fatty acids. Figure 1 shows how FFA and moisture are reduced in the two stage, continuous FAeSTER system using yellow grease. While 1% FFA is sufficient for yellow grease, finished biodiesel must be less than 0.25% FFA (acid number less than 0.5). Using Palm Fatty Acid Distillate, figure 2 shows conversion down to less than 0.25% (or 0.5 acid number) in a batch process *without caustic stripping*.

The FAeSTER process itself is a two stage reaction which will operate faster with low FFA feedstocks, and slower with high FFA feedstocks. There is no limit to the amount of free fatty acids or moisture in the incoming feed, however, higher moisture will result in a slower flow rate. Therefore less than 1500ppm moisture is suggested on incoming feedstock.

The reaction rate of CALB in the FAeSTER process is, well... fast. In figure 2, the PFAD has achieved 92% conversion in only 30 minutes. This allows the system to have a small physical footprint. For example, a 4 gallon per minute system has two, 225 gallon reactor tanks. In addition to pumps, piping, and instrumentation, the entire unit will have a footprint less than 12' x 12'. Due to the specific size and shape of the tanks, it is unlikely that retrofitting existing tanks will be an option for the FAeSTER process.

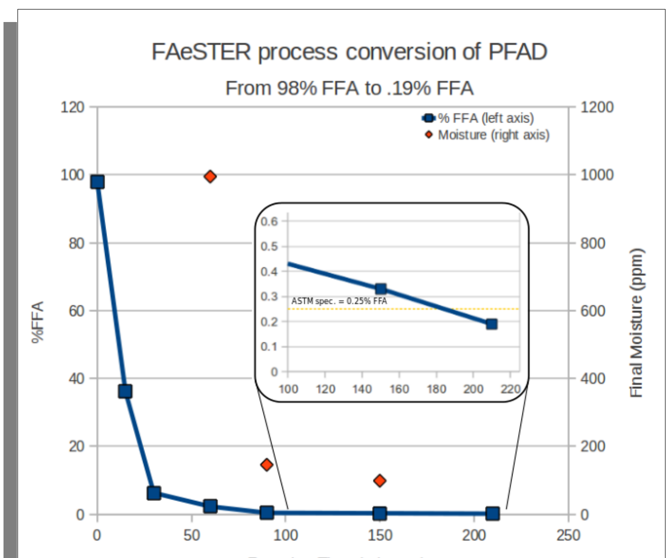

Figure 2: FAeSTER (batch) with PFAD

Finally, the FAeSTER process uses dramatically less methanol than traditional esterification (1.15:1 MeOH:FFA as compared to 20:1 for traditional acid esterification). As a result, the FAeSTER process produces less methanol which will require distillation. Overall, this simplifies the distillation requirements and decreases overall distillation throughput by 6 – 12 times as compared to traditional acid esterification.

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Process Costs and Comparison for the FAeSTER process

The enzymatic process significantly changes a biodiesel producers cost and revenue picture. We have developed a cost calculator proforma to evaluate producers' choices between traditional acid esterification and the FAeSTER process, based on the most current process data, for very high FFA feedstocks (90%+) and low FFA feedstocks (<20%). The calculator includes all costs associated with the process, and is our best effort in comparing "apples to apples".

	Traditional acid esterification	FAeSTER enzymatic esterification
Capital Cost	high	low
Catalyst Cost	low	high
Methanol Distillation Variable Cost	high	low
Footprint	large	small
Safety	uses hazardous /toxic chemicals	no hazardous/toxic chemicals
Catalyst Handling	daily	monthly or less

The data in the next few pages may not represent an accurate picture for your particular plant, and every plant will need to perform their own comparison. Please contact us to discuss your situation and to create a more accurate cost comparison specific to your company.

Process Comparison: Acid Esterification and FAeSTER Process

		High FFA Feedstock (90%+)	
		Acid esterification (sulfuric) Continuous, two stage esterification using sulfuric acid, 40:1 MeOH:FFA first stage, 20:1 second stage	**FAeSTER Enzymatic Esterification** Continuous three stage esterification using FAeSTER process
System Information	Capacity (gal / year)	3,000,000	3,000,000
	Methanol rectification (gal / year)*	**9,305,744**	**74,274**
	Final % FFA	<0.25% FFA	<0.25% FFA
	Continuous / Batch	Semi-continuous	Continuous
	Operational days per year	300 days, 24 hours/day	300 days, 24 hours/day
	Flow Rate (gpm)	35	7
Variable Cost Comparison	Variable costs per gallon		
	Methanol Rectification (heat, cooling)	$1.34	$0.01
	Catalyst Cost	$0.04	$0.16
	Total variable costs excluding feedstock and dep. and amort. (includes heat, electricity, methanol consumed, water disposal)	**$1.56**	**$0.35**
FAeSTER Advantages	**No additional methanol rectification requirements for existing plants, low capital and operating costs, minimal equipment footprint, no acidic methanol, continuous process easily adjustable to any FFA level, same equipment used for full enzymatic biodiesel production process**		

* All plants rectify and reuse any excess methanol produced. For very high FFA material using the FAeSTER process, most of the water is concentrated to 80% in methanol. This concentrated water stream is disposed of and does not go through methanol rectification, resulting in a very small rectification stream. Furthermore, the methanol which is rectified can be effectively reused at 95% purity instead of 99%+.

Process Comparison: Acid Esterification and FAeSTER Process

		Low FFA Feedstock (<20%)	
		Acid esterification (sulfuric) Continuous, single stage esterification using sulfuric acid with 20:1 MeOH:FFA methanol addition	**FAeSTER Enzymatic Esterification** Continuous two stage esterification using FAeSTER process
System Information	Capacity (gal / year)	3,000,000	3,000,000
	Methanol rectification (gal / year)*	**1,143,071**	**46,114**
	Final % FFA	<1% FFA	<1% FFA
	Continuous / Batch	Semi-continuous	Continuous
	Operational days per year	300 days, 24 hours/day	300 days, 24 hours/day
	Flow Rate (gpm)	10	7
Variable Cost Comparison	Variable costs per gallon		
	Methanol Rectification (heat, cooling)	**$0.10**	**$0.01**
	Catalyst Cost	**$0.01**	**$0.11**
	Total variable costs excluding feedstock and dep. and amort. (includes heat, electricity, methanol consumed, water disposal)	**$0.14**	**$0.15**
FAeSTER Advantages	**No additional methanol rectification requirements for existing plants, low capital and operating costs, minimal equipment footprint, no acidic methanol, continuous process easily adjustable to any FFA level, same equipment used for full enzymatic biodiesel production process**		

* All plants rectify and reuse any excess methanol produced. For very high FFA material using the FAeSTER process, most of the water is concentrated to 80% in methanol. This concentrated water stream is disposed of and does not go through methanol rectification, resulting in a very small rectification stream. Furthermore, the methanol which is rectified can be effectively reused at 95% purity instead of 99%+.

Comparison of Very High FFA (90%+) Feedstocks

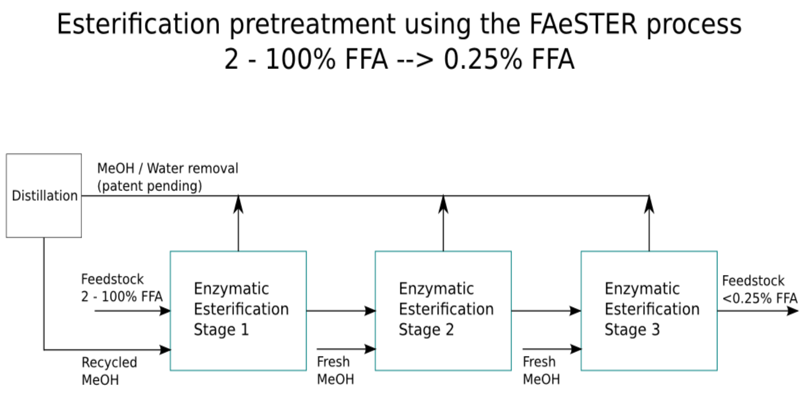

Figure 3: FAeSTER Process, 2 – 100% FFA feedstock

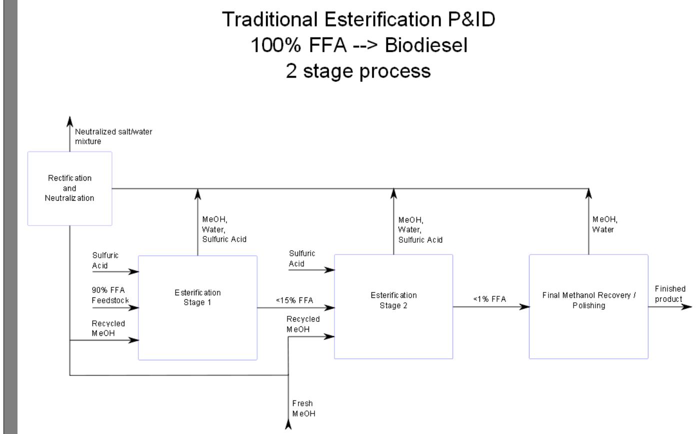

Figure 4: Acid Esterification, 90% FFA feedstock

Process Comparison: Acid Esterification and FAeSTER Process

		High FFA Feedstock (90%+)	
		Acid esterification (sulfuric)	**FAeSTER Enzymatic Esterification**
		Continuous, two stage esterification using sulfuric acid, 40:1 MeOH:FFA first stage, 20:1 second stage	Continuous three stage esterification using FAeSTER process
System Information	Capacity (gal / year)	3,000,000	3,000,000
	Methanol rectification (gal / year)*	**9,305,744**	**74,274**
	Final % FFA	<0.25% FFA	<0.25% FFA
	Continuous / Batch	Semi-continuous	Continuous
	Operational days per year	300 days, 24 hours/day	300 days, 24 hours/day
	Flow Rate (gpm)	35	7
Capital Cost Comparison	Capital Costs – New plant construction		
	Methanol rectification	$2,193,500	$150,000
	Boiler	$220,000	$25,000
	Esterification equipment	$661,250	
	Total (includes automation, feedstock drying, assembly, lab equipment, other system components, etc.)	**$3,461,921**	
	Capital Costs – Bolt-on to existing plant		
	Methanol rectification	$2,193,500	
	Boiler	$220,000	
	Esterification equipment	$661,250	
	Total (includes automation, feedstock drying, assembly, etc.)	**$3,461,921**	**Call for Pricing**
FAeSTER Advantages	**No additional methanol rectification requirements for existing plants, low capital and operating costs, minimal equipment footprint, no acidic methanol, continuous process easily adjustable to any FFA level, same equipment used for full enzymatic biodiesel production process**		

Comparison of <20% FFA Feedstocks

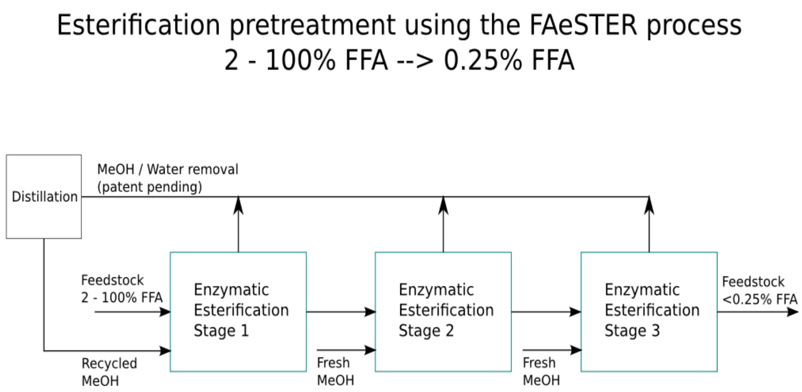

Figure 5: FAeSTER Process, 2 – 100% FFA feedstock

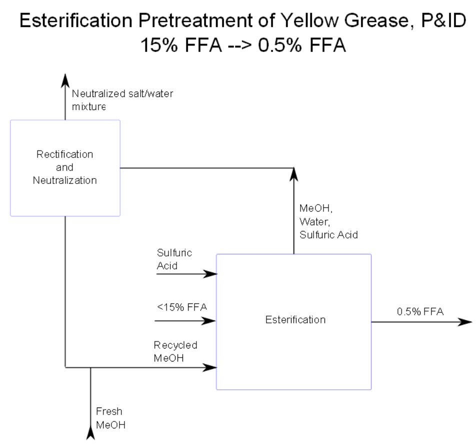

Figure 6: Acid Esterification, 20% FFA Yellow Grease

Process Comparison: Acid Esterification and FAeSTER Process

		Low FFA Feedstock (<20%)	
		Acid esterification (sulfuric) Continuous, single stage esterification using sulfuric acid with 20:1 MeOH:FFA methanol addition	**FAeSTER Enzymatic Esterification** Continuous two stage esterification using FAeSTER process
System Information	Capacity (gal / year)	3,000,000	3,000,000
	Methanol rectification (gal / year)*	**1,143,071**	**46,114**
	Final % FFA	<1% FFA	<1% FFA
	Continuous / Batch	Semi-continuous	Continuous
	Operational days per year	300 days, 24 hours/day	300 days, 24 hours/day
	Flow Rate (gpm)	10	7
Capital Cost Comparison	Capital Costs – New plant construction		
	Methanol rectification	$500,000	
	Boiler	$25,000	
	Esterification equipment	$230,625	
	Total (includes automation, feedstock drying, assembly, lab equipment, other system components, etc.)	**$998,296**	
	Capital Costs – Bolt-on to existing plant		
	Methanol rectification	$500,000	
	Boiler	$25,000	
	Esterification equipment	$230,625	
	Total (includes automation, feedstock drying, assembly, lab equipment, etc.)	**$998,296**	**Call for pricing**
FAeSTER Advantages	**No additional methanol rectification requirements for existing plants, low capital and operating costs, minimal equipment footprint, no acidic methanol, continuous process easily adjustable to any FFA level, same equipment used for full enzymatic biodiesel production process**		

Frequently Asked Questions

Do you have a transesterification system using enzymes?

Yes. as we presented at the 2012 National Biodiesel Conference, we have successfully scaled up the transesterification technique using liquid enzymes. We have met the full ASTM D6751 specification using a liquid enzymes for transesterification followed by the FAeSTER process which will "polish" any residual free fatty acids that may form during the transesterification process.

Are you using enzymes for feedstock pretreatment or esterification?

Yes. We have been using the FaeSTER process for feedstock pretreatment on our pilot plant. We have validated the FaeSTER esterification process for yellow grease, brown grease, corn oil, and palm fatty acid distillates.

Why did you focus on esterification first?

The esterification reaction is orders of magnitude faster than transesterification, even under optimized conditions. CALB, the enzyme used for esterification, is extremely stable and has not lost stability after over 80 days of continuous operation. As a biodiesel producer, we felt that focusing on an effective esterification system would have the greatest near-term impact on the industry. Also, as we learned about enzymatic transesterification, we found it was relatively easy to achieve ASTM specification for bound glycerin, but very difficult to achieve ASTM specification for acid number. The solution that we came up with to address this problem also works to esterify feedstocks – the FAeSTER process.

Therefore, we felt that the FAeSTER process serves the immediate needs of the industry – simple esterification and access to low quality feedstocks, as well as its long term needs – a way to reduce acid number in enzymatic transesterification.

Can I retrofit my existing infrastructure to save capital expenditures when switching to enzymatic esterification or transesterification?

Probably not on the esterification side, due to the specificity of the equipment, tanks, etc. It is possible that you could use existing equipment with transesterification, which can require longer reaction times and may be more appropriate for large, cone bottomed tanks. In our commercial trial for transesterification we used a 2700 gallon cone-bottom stainless steel reaction vessel, this reactor has been utilized for chemical base transesterification processes in commercial production at Piedmont.

How can I be sure that my feedstock will work in your process?

We are inviting companies interested in the FAeSTER process to send us a sample to test on a lab scale. We already have extensive data on yellow grease (used cooking oil), brown grease, and palm fatty acid distillate, so other feedstock types would be preferable. The data will provide you with information on FFA and moisture reduction for your sample on a single, small run to ensure that your desired FFA and moisture can be achieved. Once confirmed, you can test your feedstock further with a full enzyme longevity trial with the goal of achieving a catalyst cost of $0.15 per gallon or less. Longevity trials take at least a month and a significant amount of work in the lab.

The variable cost for 20% FFA feedstocks is higher for the FAeSTER process than for the traditional process. Is that correct, and will that change?

Yes, these costs are based on our most current data. However, as we continue our enzyme life trials in the lab and on the commercial scale, we expect that cost to come down near or below the cost for traditional esterification. There are also other advantages (capital cost, safety, footprint, etc.) that address the primary concerns of most biodiesel plants which been unwilling or unable to install traditional esterification.

What are the incoming feedstock specifications coming into the FAeSTER process?

Physical filtration to 50 microns or less is all that is required.

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